DEPARTMENT SUMMARY

The Oceanography Department has developed a broad research program focused on physical oceanography to meet the anticipated future needs of the Navy. Our priority basic research themes are the development of scientific capabilities to measure, analyze, and forecast fields of littoral ocean variables which occur in association with synoptic/mesoscale processes over limited regional and temporal domains. The areas of emphasis include coastal and nearshore ocean dynamics, air-sea interaction phenomena, and boundary currents. Regions of interest include the marginal sea ice zone, coastal ocean regions, and strategic straits of the world.

Our priority applied research themes are the application of analyses and forecasts of upper ocean synoptic/mesoscale variability to Naval operations. Areas of emphasis include the impact of littoral processes, eddies and boundary currents on ocean surveillance systems, the effect of coastal ocean response storms on acoustic propagations and ambient noise and the impact that the wave climate exert on nearshore processes and beach character as pertains to mine/mine countermeasure, amphibious warfare, and special forces operations.

These research themes require the development of numerical ocean prediction and synoptic oceanography capabilities. They are achieved through employment of modem dynamical and mathematical principles, numerical and statistical methods, computational and graphical facilities, and in-situ and remote sensing observation.

The diverse talents of the department faculty apply these various techniques to solve problems of common interest. Our students are actively involved in these research programs and participate in research cruises, conference presentations, and as co-authors of research reports and papers. Much of our research results, both theoretical and applied, are incorporated into the curricula we support. A summary of focus research areas follows.

COASTAL AND NEARSHORE OCEANOGRAPHY

Under sponsorship of the Office of Naval Research, Professor M.L. Batteen is using an eddy-resolving, primitive equation coastal model to study the generation, stability, and maintenance of currents and eddies in the California and Iberian Current Systems.

Professor C.A. Collins working with Professors N. Garfield and R. Paquette, continued subsurface Lagrangian measurements of flow in the California Current system. RAFOS floats were launched between Point Arguello and Cape San Martin along the upper slope to determine regions of formation of submesoscale vortices. This work was sponsored by the Office of Naval Research.

Professor C.A. Collins, with support from the National Science Foundation and the Monterey Bay National Marine Sanctuary, conducted a series of hydrographic cruises off Central California. The cruises occupied CalCOFI Line 67 to a distance of 200n. miles from shore and were designed to determine the response of local waters to El Nino conditions. Professors L. Rosenfeld and C.A. Collins also helped in the collection of current meter and sediment trap data during this time period; these observations were supported by Monterey Bay Aquarium Research Institute and were acquired at two moorings located along CALCOFI Line 67.

Professors C.A. Collins and S. Ramp, with Dr. Marlene Noble of USGS, observed currents at three moorings located near the Deep Ocean dumpsite off San Francisco. This project was sponsored by the Environmental Protection Agency.

Professor C.A. Collins continued work with the Naval Oceanographic Office to develop tactical decision aids for use in mine warfare which are based upon the characteristics of ocean currents.

Associate Professor P.C. Chu, under the sponsorship of the Office of Naval Research, has continued working on coastal ocean analysis and prediction. The major studies include: (a) two kinds of predictability in Lorenz system and ocean climate systems, (b) investigation of error propagation from winds to ocean models, (c) verification of Haney-type surface thermal boundary conditions, (d) development of a coastal atmosphere-ocean coupled system (CAOCS), (e) development of a geometric model for observational T, S data analysis, (f) identification of the South China Sea warm-core/cool-core eddies using the Navy's MOODS data, AXBT data, and the National Meteorological Center (NCEP) sea surface temperature (SST) fields (1982-94), (g) development of high-order difference schemes, (h) development and verification of P-vector inverse method, and (i) investigation of interdecadal oscillations in wind and thermally driven ocean general circulation model (OGCM).

Associate Professor P.C. Chu**,** under the sponsorship of the Naval Oceanographic Office, continued (1) to investigate environmental effects on the joint warfare simulations at various scales (e.g., theater level, technical level, ...) and to incorporate the Navy's Meteorological and Oceanographic (METOC) data and models effectively into the joint warfare

simulation models, such as RESA and mine warfare models obtained from COMMINWARCOM; (2) to estimate the value added of knowing the METOC data; and (3) to quantitative analyze the value added of knowing the environment and to identify the measure of effectiveness of METOC knowledge.

Associate Professor. P.C. Chu, under the sponsorship of NPS, has investigated the sensitivity of the Joint Simulation Systems to the environment. At the same time, he is incorporating realistic environments into high-resolution, high fidelity wargames of mine warfare.

Professor T.H.C. Herbers is investigating the dynamics of ocean surface waves in shallow coastal waters using theory and field observations. Current research projects (funded by the Office of Naval Research) focus on nonlinear wave-wave interactions, shoaling of waves on beaches, the generation of surf beat, and the propagation of waves over a continental shelf.

Professor L. Le in cooperation with Dr. P. Luong (NAVOCEANO), under multi-year sponsorship of the ONR Navy Ocean Modeling and Prediction Program (NOMP), developed a Coastal Ocean System (COS) with curvilinear nearly-orthogonal, multi-block grids, which better handle complicated coastlines, bathymetry and open boundary conditions. The generated numerical grids were coupled to the coastal ocean models with data assimilation schemes. Under the sponsorship of ONR NOMP, Professors L. Le, J. Paduan, and Dr. P. Luong (NAVOCEANO) use the Monterey Bay COS to study the response of MOB to diurnal wind and tidal forcing.

Professor J. D. Paduan, with funding from ONR and NSF, is undertaking studies of coastal circulation problems in Monterey Bay, CA and off Chesapeake Bay, VA using High Frequency (HF) radar-derived currents. Of particular interest are the coastal phenomena of sea-breeze driven currents related to sea-land temperature differences and internal tidal currents generated when sea level fluctuations interact with the sloping ocean bottom. A primitive-equation modeling study is also underway using the Princeton Ocean Model to simulate the three-dimensional generation and propagation of internal tides around the Monterey Submarine Canyon.

Professor P.-M. Poulain has continued to make direct measurements of the surface currents and the surface temperature in the Adriatic Sea using satellite-tracked drifters in order to describe the variability of the surface mesoscale structures and gain knowledge on their dynamics. This project, in close collaboration with NATO/SACLANTCEN and Italian research institutes, is sponsored by the Office of Naval Research.

Professor P.-M. Poulain**,** under the sponsorship of the Office of Naval Research, has studied the transport properties in the Adriatic basin using surface drifter data collected in 1994-96 and using a Lagrangian transport model.

Professor L. Rosenfeld is studying internal waves, particularly at tidal frequencies, in the littoral zone. She is working with Professor Paduan on model studies funded by ONR, and is making field measurements, funded by NSF with colleagues from the University of Washington.

Under sponsorship from the National Ocean Partnership Program, Professors J.D. Paduan, S.R. Ramp, C.S. Chiu, C.A. Collins, L.K. Rosenfeld, and N. Garfield began a combined observation, modeling and data assimilation program based on the network of moorings, HF radar instruments, and acoustic tomography sections around Monterey Bay. The Innovative Coastal-Ocean Observing Network, or ICON, involves science and engineering partners from seven different institutions in addition to NPS, which acts as the central point for the program.

Professor Steven R. Ramp, with funding from the Office of Naval Research and the National Ocean Partnership Program, is studying the dynamics of the continental shelf and slope along the U.S. West Coast and the circulation of the Asian marginal seas. He is presently doing a retrospective data analysis of the South China Sea and participating in the moored buoy element of the Innovative Coastal-ocean Observing Network in and around the Monterey Bay.

Professors T.P. Stanton, E.B. Thornton, and T.H.C. Herbers are participating in the Shoaling Waves DRI sponsored by ONR that will develop an improved model of surface gravity wave propagation across continental shelves. This work includes unique observations of dissipation in the wave forced bottom boundary layer, and an extensive field program at Duck, NC, in September 1999.

Professors E.B. Thornton and T.P. Stanton are developing models to predict the wave-induced three-dimensional velocity field and induced sediment transport over arbitrary bathymetry in the nearshore zone, and comparing the models to comprehensive field data they have acquired. This work is sponsored by ONR. Under a separate ONR contract, they are testing and evaluating a 3D morphodyamic model to be transitioned to the fleet.

ACOUSTICAL OCEANOGRAPHY

Professors R.H. Bourke and J.H. Wilson are analyzing transmission loss and bottom backscattering data from shallow water areas with a goal of developing a bottom reverberation algorithm for the AN/SQS-53C sonar when operating in shallow coastal waters. They have recently expanded this research to include the new helicopter sonar (ALFS) and the low frequency active (LFA) sonar. Investigations in the past year have centered on quantifying the energy spreading loss phenomenon. The sponsor is NUWC.

Professors R.H. Bourke and J.H. Wilson are developing a predictive ambient noise model for submarines operating in the Arctic Ocean which will forecast periods of extremely loud (>95th percentile level) and quiet (<5th percentile) noise levels. The ice prediction model, PIPS is being modified to produce output fields of energy disruption as an indicator of pressure ridge formation. We are also studying RADARSAT imagery to verify the response of the ice deformation field to windforcing. Sponsor is ONR.

Professor C.-S. Chiu is analyzing experimental data collected from the Shelfbreak PRIMER field study, which took place in a shelf-slope region south of New England, to (1) determine the effects of seasonal and mesoscale variability of the shelf-break frontal thermal structure on the transmission of sound from the slope to the shelf, (2) relate the temporal and spatial variability of the acoustic propagation with the ocean variability in the frontal zone, and (3) obtain tomographic maps of the frontal region for use in the characterization of the ocean variability. The research is funded by ONR.

Professors C.-S. Chiu and C. A. Collins are converting the former Pt. Sur SOSUS facility into a dual-use Ocean Acoustic Observatory for the purpose of marine research, and investigating the feasibility of tracking and counting blue whales in Central California water using this former SOSUS hydrophone array. The research is funded by SERDP/ONR.

Professor C.-S. Chiu is organizing international workshops in shallow-water acoustics to plan a collaborative international experiment in the seas of China. Such an experiment will focus on studying the physics and variability of sound propagation and scattering that are unique to the coastal waters of the Asian Pacific region. The research is funded by ONR.

Professors C.-S. Chiu and C.A. Collins are studying the California Current System using the NPS Ocean Acoustic Observatory and tomographic inverse techniques. This is part of an inter-institutional partnership project called, "Ocean Acoustic Observatory Federation." The research is funded by NOPP.

AIR-SEA INTERACTION AND OCEAN TURBULENCE

Professor R.W. Garwood has a five-year grant from the National Science Foundation to study polar sea convective instabilities. The major scientific objective of this study is to understand the coupled ocean mixed layer-ice system response to the passage of atmospheric storms. The most intense surface cooling and wind stresses in the Arctic are associated with storms, and their long-term cumulative effects on the heat and water budgets for the Arctic Ocean are predicted by including (i) realistic mixed layer physics, (ii) ice thermodynamics, and (iii) three-dimensional wind-driven ocean circulation.

Ms. Arlene Guest and Professor Garwood are in the final year of a four-year project, "Equatorial Mixed Layer System," with grant money from the National Oceanic and Atmospheric Administration and the National Science Foundation. This project is part of the TOGA Coupled Ocean Atmosphere Response Experiment (COARE), to explain large-scale feedback between the ocean and atmosphere in the Western Pacific.

Professor R.W. Garwood is sponsored by the Office of Naval Research to simulate the response of Lagrangian drifters to convection in the Labrador Sea. Understanding the drifter response will lead to optimal strategies for deployment of drifting instruments and help in the interpretation of observations obtained by instruments under the influence of oceanic convection. A key scientific objective is to understand the turbulent kinetic energy budget for free and forced deep oceanic convection, and the processes leading to deep penetrative convection in subpolar seas. The method is to use nonhydrostatic oceanic large-eddy simulation (LES) to predict the unsteady three-dimensional turbulent velocity, temperature, salinity, and pressure fields on a model grid. Typical grid domains are 1-4 km deep by 3-12 km horizontally, resolving the OPBL turbulence from the integral scale (dominant turbulent eddy size) into the inertial range. These fields are archived or used directly to advect Lagrangian drifter models (LDM's). LDM's are designed to simulate a variety of drifter designs: pure Lagrangian, isobaric, glider, or propelled (AUV's). A major milestone passed during FY98 was the large-eddy simulation of Labrador Sea convection during the 28-day ship-observed focus period of the 1997 field experiment.

Professor L. Le developed an air-wave-sea interaction model of semi-empirical turbulence and similarity theories. The model was used in the modeling of vertical distributions of turbulent dissipation in the Upper Oceanic Turbulent Layer under surface breaking wave conditions. This work was under multi-year sponsorship of ONR.

Professors W. Maslowski and R.W. Garwood have been awarded a new three-year grant from the National Science Foundation to model shelf-basin circulation and mixing in the Chuchi Sea. This grant was awarded as part of Phase I of a new Arctic Shelf-Basin Initiative.

NUMERICAL PREDICTION AND DATA ASSIMILATION

Professors J.L. McClean and A.J. Semtner, sponsored by the National Science Foundation, continue to collaborate with World Ocean Circulation Experiment (WOCE) investigators to evaluate the global 1/6-degree Parallel Ocean Program (POP) model and use a combination of POP output and WOCE data to understand ocean processes in particular basins/ regions. Efforts have concentrated on the South Atlantic, the Indonesian Through Flow, and the Pacific Ocean. In addition, output from a 1/3-degree fully global version of POP (Arctic included), forced with reanalyzed 1979-1993 European Center for Medium-range Weather Forecasts products, is also used towards this end.

Professors R. Tokmakian and A. Semtner continue to produce, analyze, and distribute output from global 1/4-degree 20-level ocean models forced by reanalyzed 1979-94 atmospheric data of the European Center for Medium-range Weather Forecasts. Recent integrations using ECMWF operational datasets have allowed the simulations to include the recent El Nino of 1997-98. This multi-year research is supported by the National Science Foundation and cost-shared by NPS. Also, a NASA grant which includes Professor J. McClean is analyzing model output to find satellite observable indicators of interannual to decadal changes in ocean circulation.

Professors A.J. Semtner, W. Maslowski, and Y. Zhang began in late FY 1998 to develop a new Polar Ice Prediction System (PIPS 3.0) under sponsorship of the Office of Naval Research. This research uses a highly parallel Arctic ice-ocean model as the foundation for improved dynamics and thermodynamics. The model will be transitioned to operational status in collaboration with scientists from Stennis Space Center.

Professors A. Semtner, R. Tokinakian, J. McClean, W. Maslowski, and Y. Zhang began a five-year project sponsored by the Department of Energy on the Application of Parallel Ocean and Climate Models to Decade/Century Prediction. The research involves many simulations of ocean-ice circulation and of ocean-atmosphere-ice interactions on long time scales, using very large supercomputers at the National Center for Atmospheric Research, Los Alamos National Laboratory, the National Energy Research Supercomputing Center, and the Arctic Region Super-computing Center. The most ambitious simulations are conducted in collaboration with investigators at the first two sites. Ocean grid sizes range from 1/3 degree to as fine as 1/10 degree, with 20-40 vertical levels. Extensive comparisons with data and detailed analyses are in progress.

MARINE OPERATIONS

Mr. P. Jessen and Professor R.W. Garwood managed shipboard support for NPS at-sea instruction and research projects off the Central California coast. Twenty-four days of operations were carried out on the RV *Pt. Sur*. Students and faculty participated in these shipboard projects from both the Departments of Oceanography and Meteorology. The sponsor for this project is the Commander, Naval Oceanography Command. NPS acquired the Point Sur SOSUS array and it is being used in a variety of reimbursable-funded research projects.

Professor J.R. Clynch conducted an effort to improve the at-sea (non-differential) OPS horizontal position from 10 m to about 1 m. The third of three at-sea experiments was conducted in 1998 in support of this goal on the RV *Pt. Sur*. This experiment contains all the elements of a possible system, multiple GPS receivers, atomic oscillator, and inertial attitude systems. For the National Imagery and Mapping Agency (NIMA), Dr. Clynch is studying the means to improve road locations in a tactical situation using commonly available OPS receivers. This study is being done with Professors Franke and Neta of the Mathematics Department. Work on Antarctic aircraft landings systems is ongoing. A system was deployed to McMurdo to monitor the environmental effects on the Mobile Microwave Landing System (MMLS) being tested in the 1998/99 operational season. The effects on the ice sheet of the landing of fully loaded CS aircraft was also measured.